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A COMMENT UPON PRESENT-DAY APPLIED GEOPHYSICS[1]

By F. W. Lee[2]

Operating engineers and mining executives are interested in the science of applied geophysics, but are looking for a simple and understandable exposition of its problems, instead of dissertations which are becoming more and more involved and increasingly difficult to comprehend.

It may be well to discuss the goal, the attempted methods of reaching it and the psychological motive, if any, back of the science. Where does the subject of applied geophysics stand from the viewpoint of (1) the physicist, (2) the mathematician, and (3) the geologist? Fundamentally, the science aims at a differentiation of subterranean geology with the object of finding useful mineral products by the study of gravitational, magnetic, seismic, electric, and other fields which may be associated with the materials naturally or which may be applied to them. The more skillfully these fields are recognized, applied, and analyzed the greater will be the possibility of interpreting results in a way that will be remunerative both economically and scientifically.

Gravitational Methods

To illustrate this fact, we have the outstanding example of exploration by gravitational methods, the physical and mathematical development of which is far in advance of electric, seismic, or other methods and which may serve as a pattern for attainment in these other fields. The physical and mathematical possibilities of gravitational methods have seemingly been reached and have become standardized so that their application is now limited only by the resourcefulness of the geologist and the complexity of the subterranean structure.

One may ask when has the physicist completed his work and when has the mathematician fully met his responsibilities, thereby giving the geologist or mining engineer useful tools to apply.

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2 - Senior physicist, U. S. Bureau of Mines.

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The physicist clearly states that the mutual attraction of matter is the prime and only physical feature involved in this case and that this attraction does not vary with the kind of material but depends solely upon its mass distribution. Furthermore, the physicist has furnished an instrument, a rather slow but quite reliable one, in the gravity variometer or torsion balance for measuring gravitational anomalies. The factors, therefore, which control gravitational methods are completely known and understood.

The mathematician has found it quite easy to compute the effect of pronounced gravitational singularities which have a simple geometrical form such as prisms, cylinders, spheres, or sections of them. Originally natural anomalies were described as singularities having the above forms, but as the science progressed it was found that these forms were not sufficiently comprehensive. The subject was reviewed by the mathematician with a view to computi a system of charts and tables which would allow a complete correlation of any distribution of mass for every possible indication of the instrument. At this period papers on the torsion balance had a very complicated mathematical aspect, but they have entirely clarified what at one time appeared to be an insurmountable difficulty.

As a result this work has given the geologist a comprehensive system which he can use with the utmost confidence.

Such a simple straightforward evaluation or development is not equally characteristic of some of the other methods. With these, there are generally several physical factors which enter into the observed phenomena instead of only one, as in the gravitational method.

Magnetic Methods

In the magnetic method, for example, the direction of magnetization as well as directed permeability or susceptibility must be taken into account, so the problem of the physicist is much more complicated, although with certain assumptions this field is analogous to that of gravity and should be solved similarly. At present no complete charts are published for magnetic evaluations. Singularities existing in the ground have heretofore been used as a lead in this method but are now being gradually replaced by more comprehensive methods similar to those used with the torsion balance. From the geological viewpoint magnetic susceptibilities afford means of further differentiating geological structure in a way quite similar to that used in gravity methods.

The physicist has determined the variable factors but has not classified all material relative to them. He has provided an instrument amply simple and sensitive for making magnetic field observations. The mathematician has not quite given us the ultimate solution but is in a fair way of doing so. Taking observations and correlating the geology is as facinating as ever and much more comprehensive than with the old dip needle.

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Electrical Methods

In methods which differentiate geologic structures by electrical conductivity or other electrical properties, progress has been much slower. While the technique of measurement has been sufficiently developed to meet all practical needs, the mathematics involved is still in a chaotic condition. The simple assumptions upon which mathematicians build do not naturally exist in electrical methods and the estimated factors are as yet so complicated and numerous as not to make possible the thorough, systematic, and complete analysis that is had in the gravitational method. However, because of the great possibilities inherent in electrical methods, even though very complicated, they are of great importance to the progress of the art. Undoubtedly the mathematics and technique of the methods will be more highly developed when they are as thoroughly understood and correlated as are the gravity methods.

Seismic Methods

From the physicist's point of view seismic methods fall into a branch of physics referred to as elastic deformation. The first elemental law in this branch teaches that nine coefficients are necessary in order to determine completely the form of a body under a generalized stress. For a simple medium like water six of these coefficients disappear and the other three have the same value; in other words, water is equally compressible along any axis and will not support torsional stresses. By careful grouping of these coefficients deformation can always be described as an expansion or contraction combined with a twist or torsion. While this describes the generalized condition in a medium, the situation becomes more complicated at the boundaries of geologic beds by the system of energy transfer across these boundaries. Much remains for the physicist to do in accurately describing what happens under the simplest specified condition. Although the seismic method has been applied quite successfully as a refraction or reflection method, its complete analysis has never even been attempted. The mathematician can set up a system of general equations which would describe any possible situation, but no one would be able to fit the physical picture to the equations. In regard to the instruments used in the seismic method there is still much discussion as to whether it is more desirable to measure acceleration, velocity, or simply displacement. An accurate determination of displacement would probably be most desirable, since from it the others may be singularly determined; that is, without integration factors. Most of the recording instruments have their inertial system reacting with that of the incoming impulses and since the moving impulse is the important factor, especially in character study, the matter of instrument construction is in no way settled.

From the geologist's point of view the time-space relation of the wave front has greatly helped in determining the horizon of certain geological features as well as the presence of unconformities such as salt domes.

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In this, as well as in all other systems, it is most desirable continuously to check observations against known geological conditions as a basis for proper correlation.

Because of the great flexibility in the application of mechanical energy to the ground and the ground's sensitiveness to stress, seismic methods promise very comprehensive systems of subterranean differentiation.

Geothermal Methods

Geothermal methods require boreholes and wells for their application but since these holes in themselves directly disclose the geologic structure it would seem that geothermal methods will not have much value. Slight reflection will show that a close study of temperature horizons give a good index concerning the material below them. Here the physicist has for his basis the thermal conductivity of material but his task is complicated by diverse thermal sources. The mathematician has his foundation in Fourier analysis with established boundary conditions. The problems are not nearly as simple as in gravitational methods, but they can be reduced to such form as to allow of interpretation by the geologist. Much work has been done on the determination of temperature horizons and gradients but little on the quantity of heat transmitted. The technique of measurement of temperature is well established, but the technique of measuring heat flow is much more difficult. To draw a comparison, voltages can be measured easily but not current. In other words, half of the story is lacking. The measurement of the number of calories emitted per square meter over various areas and its correlation to geology would prove most interesting.

Radioactivity Methods

Radioactivity methods from the standpoint of the physicist are well understood, and the methods of measurement are well developed in the radium-emanation electrometer and the gamma-ray electroscope, the former especially developed by Ambronn for prospecting, the latter by Kohlhörster for geophysical investigation. From the nature of the phenomena radioactivity methods do not admit of great mathematical development, but lead directly to geological application. Nevertheless, there are some interesting scientific questions which should be settled. For example, will emanation and gamma-ray surveys lead to the same geological interpretations?

Self-potential Methods

The self-potential methods still remain for consideration. These are well understood by the physicist and he can make the measurements involved with sufficient accuracy. Since the factors which control self-potential methods are of such variable nature these methods do not lend themselves to such careful work as the more standard methods do. From the mathematician's point of view they would be hopelessly complicated for full evaluation. Nevertheless, under certain geological conditions they have proved invaluable in

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prospecting for sulphide deposits. They aid in discovering great buried electrical singularities, but do not lend themselves to much further physical or mathematical development.

To the same degree that various portions of the earth differ geologically they differ in their geophysical reactions. Each portion of the earth when examined from the geophysical angle will present something new and require special indexing. Examined from this viewpoint the geophysicist, like the geologist, will never finish his work. He will also derive much pleasure in solving geological problems from the information obtained from geophysical measurements.

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